OVERVIEW OF NASA GLENN SEAL DEVELOPMENT PROGRAM

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2000 NASA Seal/Secondary Air System Workshop

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October 25-26, 2000
NASA Glenn Research Center
Administration Bldg. Auditorium

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NASA Glenn hosted the Seals/Secondary Air System Workshop on October 25-26, 2000. Each year NASA and our industry and university partners share their respective seal technology developments. We use these workshops as a technical forum to exchange recent advancements and “lessons-learned” in advancing seal technology and solving problems of common interest. As in the past we are publishing two volumes. Volume I will be publicly available and individual papers will be made available on-line through the web page address listed at the end of this chapter. Volume II will be restricted under International Traffic and Arms Regulations (I.T.A.R.)

2000 NASA Seal/Secondary Air System Workshop

Wednesday, Oct. 25, Morning:

Registration	**7:15 a.m.–8:00 a.m.**
Introductions	**8:00 a.m.–8:30 a.m.**
Introductions	Dr. Bruce Steinetz, Bob Hendricks/NASA GRC
Welcome to NASA Glenn	Dr. Woodrow Whitlow, R&T Dir./NASA GRC
Overview of NASA Glenn Seal Development Program	Dr. Bruce Steinetz/NASA GRC
Program Overviews and Requirements	**8:30 a.m.–10:30 a.m.**
Welcome to the Airline Industry	Ms. Sherry Soditus /Mr. Jim Uhl/United Airlines
Design of Critical Components	Bob Hendricks,Erv Zaretsky/NASA GRC Ms. Sherry Soditus/United Airlines
Overview of Ultra-Efficient Engine Technology (UEET) Program	Dr. Joe Shaw/NASA GRC
Overview of USAF Propulsion	Dr. Otha Davenport/WPAFB
Overview of NASA's Access to Space Programs	Mr. Harry Cikanek/NASA GRC
Break	**10:30–10:45 a.m.**
Advanced Seal Development Session I	**10:45 a.m.–12:30 p.m.**
Development of an Enhanced Thermal Barrier for RSRM Nozzle Joints	Mr. Paul Bauer/Thiokol
Advanced Seals at GE Research & Development Center	Dr. Ray Chupp, Norm Turnquist/GE-CRD
GE90 Demonstration of Aspirating Seal	Dr. Tom Tseng/GEAE
Advanced Aspirating Seal	Mr. Alan McNickle/Stein Seal
Development of High Misalignment Carbon Seals (UEET)	Mr. Lou Dobek/PW; G. Szymborski/Stein Seal
Lunch Main Cafe	**12:30 p.m.–1:30 p.m.**

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The first day of presentations included overviews of a variety of NASA, commercial airline, military and Access to Space programs. Dr. Steinetz presented the the NASA seal development program. Ms. Soditus presented United Airline's end-user's perspective of turbine engine seal/secondary air systems. Mr. Davenport summarized some recent Air Force experience with turbine engine seal and secondary air systems. Mr. Cikanek of NASA's Space Project office summarized NASA's Access to Space Programs citing areas where advanced seals are required.

Representatives from GE, P&W and Honeywell engine companies provided insight into their advanced seal development programs. Thiokol presented results of investigations applying the NASA braided carbon rope as a thermal barrier for the Shuttle Reusable Solid Rocket Motor Nozzle redesigned joints to prevent hot gas effects on critical Viton O-rings.

2000 NASA Seal/Secondary Air System Workshop
Wednesday, Oct. 25, Afternoon:

Advanced Seal Development Session II	**1:30 p.m.–4:00 p.m.**
Finger Seal Development for a Combustor Application	Dr. Arun Kumar/Honeywell Engines
High Temperature Performance Evaluation of a Compliant Foil Seal	Dr. James F. Walton III, H. Heshmat/Mohawk
Large-diameter Spiral Groove Face Seal Development	Dr. Xiaoqing Zheng/Perkin-Elmer
Abradable Seal Developments at Technetics	Mr. Doug Chappel, H. Howe/Technetics
High Temperature Metallic Seal Development	Dr. Amit Datta/Adv. Components & Materials
NASA High Temperature Turbine Seal Rig Development	Mr. Irebert Delgado/NASA Army Program M. Proctor, B. Steinetz/NASA GRC
Calibration of Optical Pyrometer System for Non-Contacting Temperature Measurement	Mr. Jay Oswald/CWRU, B. Steinetz/NASA
Break	**4:00 p.m.–4:15 p.m.**
Turbine Cavity Seal Flow Studies	**4:15 p.m.–5:15 p.m.**
UTRC Turbine Rim Seal Ingestion and Platform Cooling Experiments	Dr. John Feiereisen/UTRC
Investigation of a Shrouded Rotor-Stator Disk Cavity	Dr. Ram Roy/Arizona State Univ
Coupled Main/Cavity Flow Calculations Using TURBO/SCISEAL	Dr. Mahesh Athavale/CFDRC
Social Hour at GRC	**5:30 p.m.–6:00 p.m.**
Dinner at Mallorca restaurant with individual checks	**7:00 p.m.–?**

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Representatives from seal vendors Stein Seal, Perkin-Elmer, Technetics, Advanced Components and Materials presented their company’s recent seal development status.

Researchers from NASA Glenn presented a status review of the new High Temperature, High Speed Turbine Seal rig and associated non-contacting rotor temperature measurement system.

Researchers from United Technology Research Center, Arizona State and CFDRC presented experimental and analytical investigations into the complex flow patterns in rim seal/cavity locations in modern turbine engines. Studies have shown that excessive amounts of flow (up to 2-3% core flow) go through rim seals beyond that which is needed for cooling purposes (Munson and Steinetz, 1994). Hence SFC reductions are possible by reducing flows to what is needed for cooling purposes. New concepts and analytical methods are being developed to limit cooling to the appropriate level and provide positive out-flow of coolant preventing ingestion of hot combustion gases into the turbine rim cavity due to unsteady effects.

2000 NASA Seal/Secondary Air System Workshop

Thursday, Oct. 26, Morning:

Registration	**7:45 a.m.–8:30 a.m.**
Space Propulsion/Vehicle Seal Development I	**8:30 a.m.–10:00 a.m.**
Overview of X-37 Program and Seal Development	Dr. Todd Steyer/Boeing
X-38 Seal Development	Dr. Don Curry, R. Lewis/NASA JSC; J. Hagan/Lockheed-Martin
Rudder/Fin Seal Investigations for the X-38 Re-entry Vehicle	Mr. Pat Dunlap, B. Steinetz/NASA GRC D. Curry/NASA JSC
Control Surface Seal Development for Future Re-entry Vehicles	Mr. Juris Verzemnieks, C. Newquist/Boeing
Break	**10:00 a.m.–10:15 a.m.**
Space Propulsion/Vehicle Seal Development II	**10:15 a.m.–12:00 a.m.**
Thermal Barriers	Mr. Dennis Barber/Oceaneering
Overview of Thermal Barrier/Seal Development at HiTemp Insulation	Mr. Sieg Bork/HiTemp Insulation
Rope Seal Developments	Mr. Bruce Bond/Albany Techniweave
NASA GRC Cryogenic Seal Test Rig Capability	Ms. Margaret Proctor/NASA GRC
Lunch Main Cafeteria	**12:00 a.m.–1:15 p.m.**

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Presentations on the second day concentrated on space vehicle/propulsion seal developments. NASA is developing both the X-37 and X-38 vehicles to demonstrate technologies for each of their respective missions. Both vehicles will be taken to low earth orbit via the Space Shuttle and demonstrate on-orbit and re-entry technologies. Boeing presented an overview of the joint NASA/Air Force X-37 program, control surface seal requirements, and candidate seal approaches. NASA Johnson presented an overview of the X-38 program, control surface seal requirements, and candidate seal approaches. The X-38 is an X-vehicle that is a precursor vehicle to the Space Station Emergency Crew Return Vehicle. Dunlap and Verzemnieks presented work on developing and testing control surface seals for the X-vehicles mentioned.

Representatives from Oceaneering, HiTemp Insulation, and Albany-Techniweave presented structural seals developed for space vehicle thermal protections systems and turbine engine applications.

Proctor presented an overview of NASA Glenn’s cryogenic seal test capabilities.

2000 NASA Seal/Secondary Air System Workshop

Thursday, Oct. 26, Afternoon:

Advanced Materials Development	**1:30 p.m.–2:30 p.m.**
Overview of CMC Development Activities in NASA’s Ultra-Efficient Engine Technology (UEET) Program	Mr. David Brewer/NASA/Army Program
Overview of NASA Studies on High-Temperature Ceramic Fibers	Dr. James DiCarlo/NASA GRC
High Temperature Ceramic Fiber Development and Trends	Dr. David Wilson/3M
Special Topics	**2:30 p.m.–3:00 p.m.**
An Introduction to TRIZ	Mr. Dana Clarke/Ideation Int’l
Tour of NASA Seal Facilities	**3:00 p.m.–4:00 p.m.**
Adjourn	**4:00 p.m.**

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Representatives from NASA Glenn presented GRC’s high temperature ceramic matrix composite and ceramic fiber developments. 3-M presented property comparisons for their Nextel fibers and YAG fibers.

Ideation presented an overview of the Theory of Inventive Problem Solution (TRIZ/TIPS). TRIZ problem solution is based on research done by Genrich Altshuller (Altshuller, 1996) who extracted cause and effect solution methods from the patent literature to arrive at a systematic solution approach to obtain elegant solutions in both the original field and quite different fields of application.

Scope of Activities: Turbine Seals

Objective:

Develop durable, low-leakage turbomachinery seals to meet demands of next generation subsonic and supersonic engines

Specific Goals:

- Develop seal technology to reduce specific fuel consumption (SFC) • 2%
- Validate seal performance and design models through lab. testing under simulated speeds to (1500 fps), temperatures (to 1500°F) and pressures
- Investigate non-contacting, non-wearing seals to meet life and speed requirements
- Demonstrate seal performance in full scale engine tests
- Transition seals to engine service by 2005

Key Facilities:

In House:

- Turbine engine seal test rig upgraded to 1500°F, 1500 fps speed
- Army T-700 & T-55 engines

Contractor: Numerous laboratory facilities including full scale engine tests (GE90)

Partners:

GE; PW; Allison; Air Force; Army; UTRC; Honeywell (AlliedSignal); Williams; Perkin Elmer (EG&G); Stein Seal; Mohawk

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The objective of the NASA Glenn turbine engine seal development program is to develop durable, low-leakage seals to meet demands of next generation subsonic and supersonic engines.

Advanced seals that include film riding aspirating, compliant foil, and advanced finger seals are being investigated to demonstrate non-contacting, low-leakage operation. Advanced test rigs such as NASA GRC's unique high speed (1500 fps) and high temperature (1500ºF) turbine seal rig will be used to assess performance characteristics of these new seals. Under contract, GE will perform engine tests of a full scale (36" diameter) aspirating seal in a ground-based GE-90 engine.

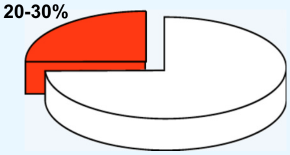
Analytical methods such as the coupled TURBO/SCISEAL code are being developed under contract with CFDRC to perform coupled main-flow (TURBO) and secondary air/seal (SCISEAL) calculations.

Why Seals?

AST Study Results: Expected Seal Technology Payoffs		
Seal Technology	Study Engine/ Company	System Level Benefits
Large diameter aspirating seals (Multiple locations)	GE90-Transport/ GE	–1.86% SFC –0.69% DOC+1
Interstage seals (Multiple locations)	GE90-Transport/ GE	–1.25% SFC –0.36% DOC+1
Film riding seals (Turbine inter-stage seals)	Regional-AE3007/ Allison	> –0.9% SFC > –0.89% DOC+1
Advanced finger seals	AST Regional/ Honeywell	–1.4% SFC –0.7% DOC+1

UEET Program Goal

Reduce Fuel Burn by 8-15%



- Seals provide high return on technology $ investment
  - Same performance goals possible through modest investment in the technology development
    - Example: 1/5th to 1/4th cost of obtaining same performance improvements of re-designing/re-qualifying the compressor
- Seal contribution to program goals: 2 to 3% SFC reduction

Advanced Seal Technology: An Important Player

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Cycle studies have shown the benefits of increasing engine pressure ratios and cycle temperatures to decrease engine weight and improve performance in next generation turbine engines. Advanced seals have been identified as critical in meeting engine goals for specific fuel consumption, thrust-to-weight, emissions, durability and operating costs. NASA and the industry are identifying and developing engine and sealing technologies that will result in dramatic improvements and address each of these goals for engines entering service in the 2005-2007 time frame.

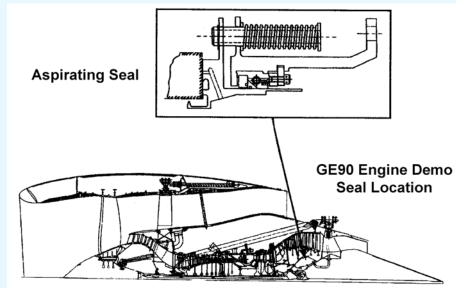
General Electric, Allison and AlliedSignal Engines all performed detailed engine system studies to assess the potential benefits of implementing advanced seals. The study results were compelling. Implementing advanced seals into modern turbine engines will net large reductions in both specific fuel consumption (SFC) and direct operating costs including interest (DOC+I) as shown in the chart (Steinetz et al, 1998).

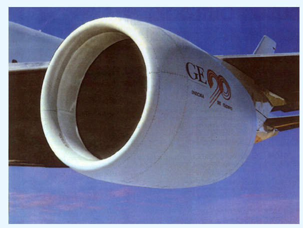
Applying the seals to just several engine locations would reduce SFC 2 to 3% . This represents a significant (20-30%) contribution toward meeting the overall goals of NASA's Ultra-Efficient Engine Technology (UEET) program.

Aspirating Seal Development: GE90 Demo Program

Funded UEET Seal Development Program

- **Goal:**
  - Complete aspirating seal development by conducting full scale (36 in. diameter) aspirating seal demonstration tests in GE90 engine.
- **Payoffs:**
  - Leakage <1/5th labyrinth seal
  - Operates without contact under severe conditions:
    - 10 mil TIR
    - 0.25°/0.8 sec tilt maneuver loads (0.08" deflection!)
  - Decrease SFC by 1.86% for three locations
- **Approach:**
  - Seal and runner design and fabrication
  - Seal system CFD analysis
  - Instrumentation and installation
  - GE90 engine test
  - Data analysis and report
- **Schedule:**
  - Design and analyses by 1Q FY01
  - Hardware fabrication by 3Q FY01
  - GE90 engine test from 4Q FY01 to 1Q FY02
  - Data analysis and report by 1Q FY02
- **Partners: GE/Stein Seal/CFDRC/NASA GRC**





General Electric GE90

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General Electric is developing a low leakage aspirating face seal for a number of locations within modern turbine applications. (see also Tseng, 2001 in this workshop proceeding for further details). This seal shows promise both for compressor discharge and balance piston locations. The seal consists of an axially translating mechanical face that seals the face of a high speed rotor. The face rides on a hydrostatic cushion of air supplied through ports on the seal face connected to the high pressure side of the seal. The small clearance (0.001-0.002 in.) between the seal and rotor results in low leakage (1/5th that of new labyrinth seals). Applying the seal to 3 locations in a GE90 engine can lead to >1.8% SFC reduction. GE Corporate Research and Development tested the seal under a number of conditions to demonstrate the seal's rotor tracking ability. The seal was able to follow a 0.010 in. rotor face total indicator run-out (TIR) and could dynamically follow a 0.25° tilt maneuver (simulating a hard maneuver load) all without face seal contact.

The NASA GRC Ultra Efficient Engine Technology (UEET) Program is funding GE to demonstrate this seal in a ground-based GE-90 demonstrator engine in early 2002.

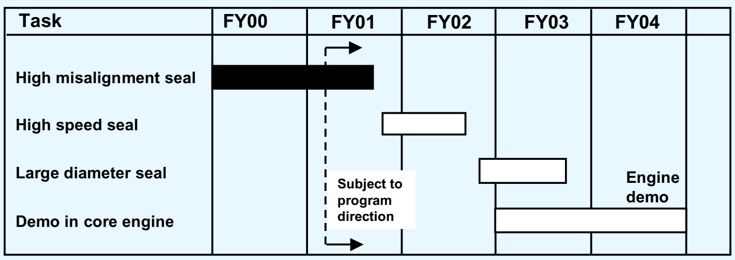
PW Bearing Compartment Seal Program PW-11

Funded UEET Seal Development Program

Objectives:

- Develop high misalignment seals capable of handling extremely large radial displacements due to angular and radial misalignment.
- Develop high speed seals that will meet life requirements at high temperatures
- Develop large diameter (up to 16 in.) seals operating at low delta P
- Develop seal technology ready for 2004 demonstrator

Schedule:



Partners: PW/Stein Seal/NASA GRC

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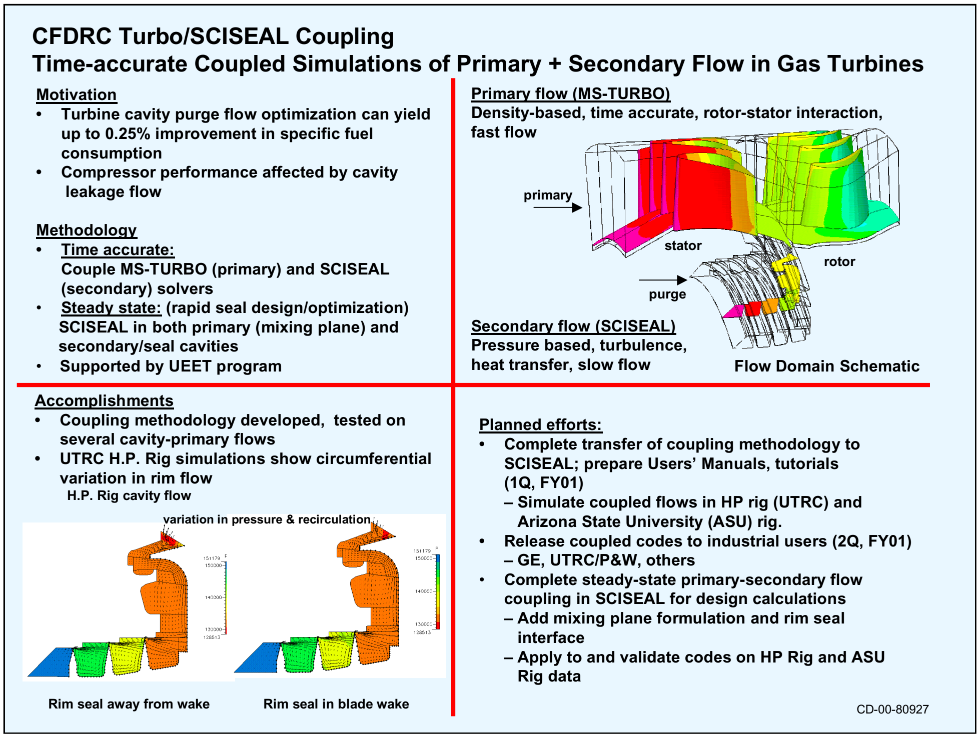
Advanced engines may incorporate geared fans. In the fan location, large bending loads coupled with structural weight limits result in fan bearing compartment seal deflections much greater than conventional carbon face seal capabilities. P&W is under contract with NASA GRC to investigate candidate carbon face and annular seals capable of large angular and radial movements. Working with Stein Seal, P&W is investigating candidate concepts designed for large angular (0.5°) and radial (0.105”) movements and testing them under laboratory conditions (see also Dobek et al, 2001 in this workshop proceedings for further details). Advancements made in this program could have immediate application to main shaft bearing compartment seals.



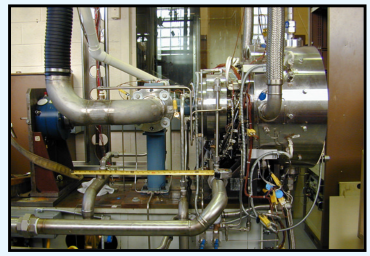
NASA contracted CFDRC to develop a coupled main flow path/ secondary air system solver to investigate complex main/turbine cavity/rim seal flow phenomenon.

CFD- Research Corporation has completed the coupling of TURBO and SCISEAL for analyzing the complex main stream (TURBO) and secondary air stream (SCISEAL) interactions, including the effects of vane/blade wake interactions. The package can analyze flows from the engine centerline through the turbine rim seal location and through main flow path.

NASA also contracted with UTRC to measure the steady/unsteady turbine rim seal/cavity flows to assess the performance of baseline turbine rim seals. CFDRC has used this data set to validate the coupled TURBO/SCISEAL code. Beta release of the codes is expected in fall 2001.

NASA GRC High Temperature Turbomachinery Seal Test Rig

Goal: Test turbine seals at speeds and temperatures envisioned for next generation commercial and military turbine engines.



- **Temperature** — **Room Temperature thru 1500°F**
- **Surface Speed** — **1500 fps at 40,455 RPM, 1600 fps at 43,140 RPM**
- **Seal Diameter** — **8.5" design; other near sizes possible**
- **Seal Type** — **Air Seals: brush, finger, labyrinth, film riding rim seal**
- **Seal Pressure** — **100 psi at 1500°F: Current (Higher pressures at lower temperatures)**
- **Motor Drive** — **60 HP (60,000 RPM) Barbour Stockwell Air Turbine with advanced digital control for high accuracy/control**
- **Financial Support: TCT, HSR, UEET, Air Force, Other**

Test rig is one-of-a-kind. More capable than any known test rig in existence.

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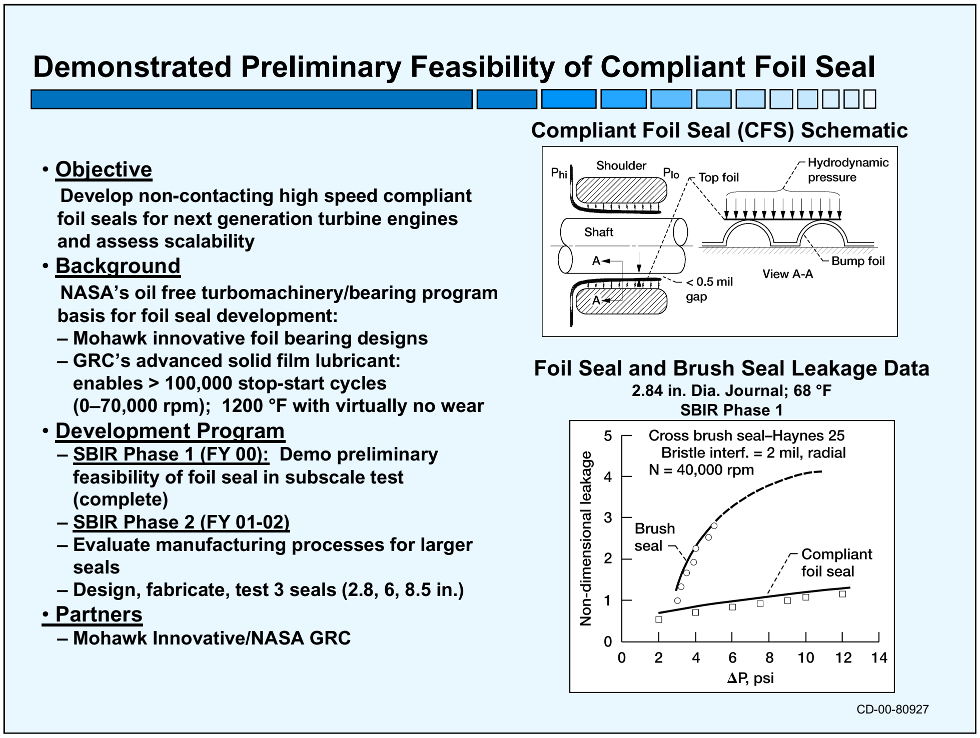
NASA GRC has finished mechanical installation of the new high speed (1500 fps), high temperature (1500ºF) turbine seal test rig. This test rig is capable of evaluating turbine seals (e.g. brush, finger, labyrinth) at all speeds and temperatures envisioned for next generation commercial and military turbine engines.

As of October 2000, the following tasks must be completed before testing will commence: complete programmable logic controller programming, complete internal rig heater functional check-out, complete lubrication system checkout, and perform overall rig functional checkout tests. Recently, the high temperature air heater passed a re-certification hydro-test enabling us to reach higher pressures (up to 100 psi) at 1500ºF.

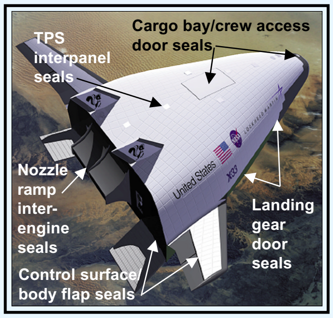


NASA has awarded to Mohawk Innovative Technology an SBIR Phase II to investigate film-riding compliant foil seals (see presentation by Walton et al, 2001 in this workshop proceedings for further details). Compliant foil seals(CFS) are derived from foil bearing technology and block flow between high and low pressure cavities through very narrow gaps between the shaft and the foil. The hydrodynamic lift between the seal and the shaft prevents rotor-seal contact during operation. High temperature solid film lubricants applied to the shaft prevent wear during start-up and shut-down when limited contact occurs (DellaCorte, 2000).

As shown in the figure, leakage is very low due to the small (<0.0005 in.) clearance between the top foil and shaft. The compliant foil seal leakage is about 1/3rd that of a comparably sized brush seal at 10 psi. Because of the non-contacting, non-wearing nature of the CFS, this very low leakage characteristic should remain with cycling. Brush seal leakage, however, increases with cycling as the brush seal bristles wear to an operating clearance.

Scope of Activities: Structural Seals

Objective:
Develop unique structural seals for extreme temperature engine, re-entry vehicle, and rocket applications.



Specific Goals:
- Develop advanced structural seals capable of extreme (1500 – 5500 °F) temperatures.
- Exploit novel design techniques to meet leakage, durability, and resiliency (spring-back) goals across operating temperature range.
- Evaluate seal performance through compression, flow and extreme thermal tests.
- Develop/validate analytical models to predict leakage and resiliency performance.
- Demonstrate seal performance through prototype system tests.

Key Facilities:
In House:
- High temperature (1500 °F) rope seal flow and compression test rigs.
- Engine components lab (>2000 °F) & C-22 Rocket Facility (5130)
- Planned: 2200+ °F compression test rig, Ames arc jet control surface seal fixture.

Partners:
Thiokol, Albany-Techniweave; Rocketdyne; Boeing; Air Force; Williams; Other Industrial Partners.

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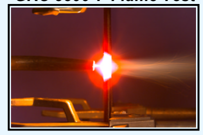
NASA GRC is also developing unique structural seals for extreme temperature engine (air breathing hypersonic and other), re-entry vehicle, and rocket applications. Challenges in these areas are extreme temperatures (1500-5500ºF), large (up to 3”) deflections, and pressures (100 - 1000 psi). Novel concepts are being developed that can satisfy these conditions while retaining their ability to follow adjacent wall movement. Seals are being constructed using advanced manufacturing techniques (e.g. braiding/weaving, other) from a range of high temperature carbon and ceramic materials.

NASA has unique facilities to evaluate the flow and durability performance of these seals at temperatures up to 1500ºF (existing) and up to 3000ºF (planned). NASA GRC also possesses a high heat flux H2/O2 rocket engine for subjecting materials and components to the extreme conditions anticipated in next generation Reusable Launch Vehicle (RLV) propulsion systems.

NASA GRC Seal Development for Space Transportation Programs

Current:



GRC 5500°F Flame Test

Shuttle RSRM Thermal Barrier Development

- **Developed thermal barrier for Thiokol to block hot (5500•F) gases from damaging RSRM Viton O-rings.**

X-38 Emergency Crew Return Vehicle Control Surface Seal Testing

- **Evaluating control surface seals for JSC for X-38 (C.R.V. demonstrator)**
- **Goal: Determine if seal flow rates are low enough to prevent hot, re-entry gas ingestion/damage of control surface hardware. Assist in advanced concept development**

RLV Inter-engine Seal Development:

- **Performed for Rocketdyne conceptual design of inter-engine seal showing promise of accommodating large 1-3” deflections in hot 3000+•F flow environment between aero-spike engine modules. Program discussions continuing.**

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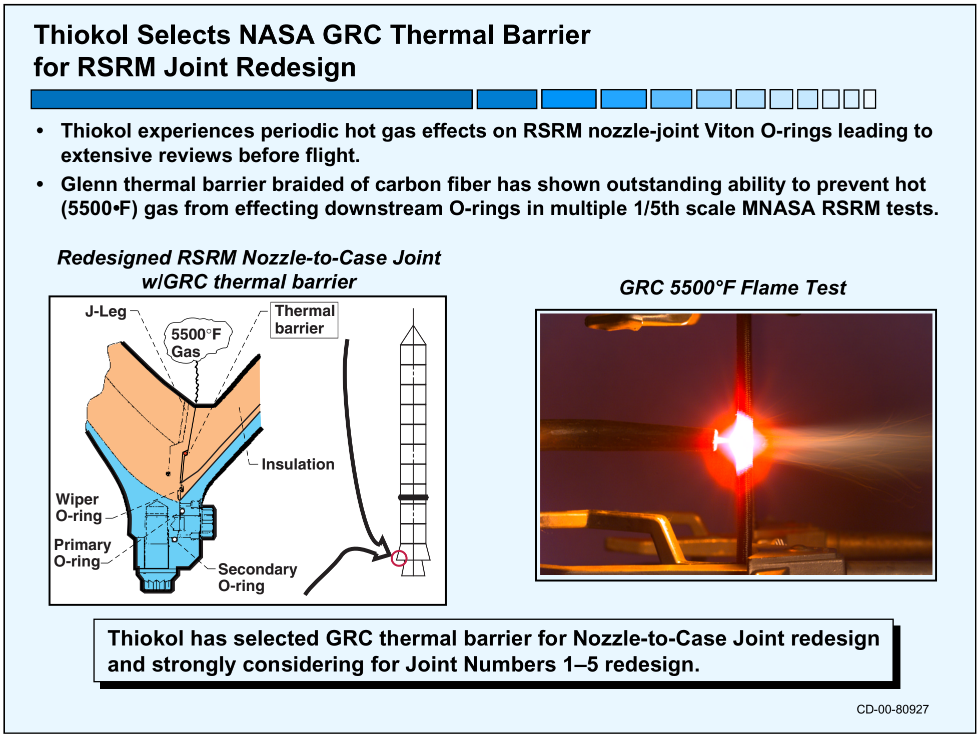
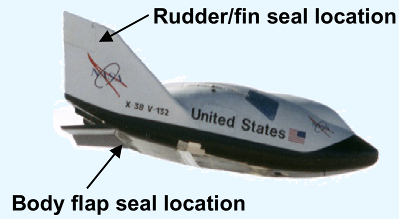
NASA GRC is contributing seal technology to the Space Shuttle, X-38, and RLV/X-33 programs. NASA GRC has developed a thermal barrier for Thiokol (supplier of solid-rocket-motors for the space shuttle) to block the hot (5500ºF), pressurized (1000 psi) gases from damaging the solid-rocket-motor nozzle joint Viton O-rings (see detail next slide). For NASA Johnson, GRC is assisting with measuring seal flow rates and resiliency to assist in determining if Shuttle-derived thermal barriers will meet the X-38 rudder-fin flow-blocking requirement (see detail two slides forward). GRC has also performed a conceptual design of an inter-engine nozzle-ramp seal showing promise of accommodating the anticipated large (1-3”) deflections in the hot (3000ºF) nozzle flow environment.



The NASA Glenn developed braided carbon fiber thermal barrier is the primary candidate being considered by NASA and Thiokol for the redesign of the space shuttle re-usable solid-rocket-motor (RSRM) nozzle-to-case joint and for nozzle joint 2. Incorporation of the NASA Glenn developed braided carbon fiber thermal barrier into the nozzle joints of the space shuttle RSRMs would eliminate hot gas penetration to nozzle joint Viton O-rings and prevent extensive reviews that delay shuttle launches.

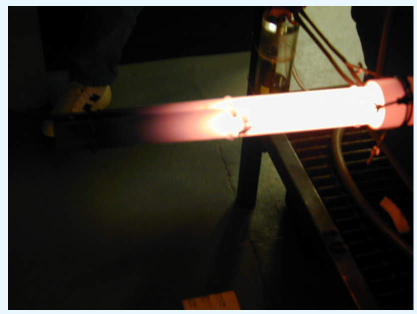
On August 10, 2000, a NASA Glenn developed braided carbon fiber thermal barrier was successfully evaluated in an MNASA reusable solid rocket motor (RSRM) at NASA Marshall (see also Bauer 2001, in this workshop proceedings for further details). The MNASA RSRM is a 1/5th-scale version of the full-scale RSRMs used to launch the space shuttle. Tested in a redesigned nozzle-to-case joint, an intentional flaw in the nozzle insulation allowed hot combustion gases to reach the thermal barrier. Soot was observed on hardware upstream of the thermal barrier, but none was seen on the downstream side. Post-test inspection revealed no damage or erosion to either the thermal barrier or to downstream O-rings that the thermal barrier is designed to protect. (see also Steinetz and Dunlap, 2000, for further details). Full scale static motor tests are planned for the Spring (nominal joint) and Fall (flawed joint) of 2001 in preparation for certification for space shuttle flight in 2003/2004.

X-38 Control Surface Seal Exposure Testing at GRC



- JSC predicts that temperatures for Rudder/Fin seal will likely reach 1900+ °F

- GRC performs furnace exposure tests on X-38 seal in compressed state at 1900°F and pre-and post-exposure flow tests



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The X-38 vehicle is being developed as a precursor to a future Crew Return Vehicle to demonstrate necessary re-entry vehicle technologies including controls surface seals. For cost considerations, JSC is interested in using space shuttle thermal barrier/seals as control surface seals. NASA Johnson asked GRC to assist them in assessing sealing performance of the rudder/fin seal being considered for the X-38 vehicle.

NASA GRC has performed a range of compression (e.g. spring-back) and flow tests on thermal barriers in both their as-received and post- high temperature exposure (1900ºF) conditions (see Dunlap and Steinetz, 2001 in this workshop proceedings for further details). The GRC tests showed that most of the thermal barrier/seal’s resiliency - was lost after the 1900ºF exposure test. These tests aided JSC in setting limits on acceptable gap openings in the rudder-fin location to prevent possible gap opening during re-entry due to seal permanent set. The flow tests also provided much needed permeability data for the JSC seal/gap thermal modeling effort.

Spaceliner–100/TPS–20 Control Surface Seal Development

Objective

- Develop and evaluate control surface seals for next generation re-entry vehicles

Approach

- Select candidate Shuttle-derived and current-technology seals
- Evaluate flow and thermal performance in relevant test fixtures
- Carefully measure aero-thermal heat loads under arc jet heating rates with
  - multiple seal gap conditions
  - control surface deflection into flow
- Use database to validate aero-thermo models to enable prediction of seal performance under actual re-entry conditions.

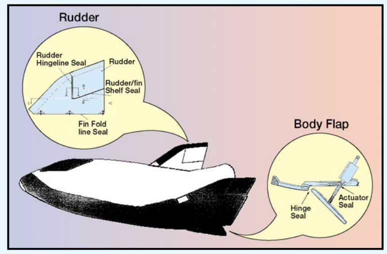
Schedule

- Complete arc jet tests 1Q FY01
- Validate aero-thermal models 2Q FY01
- Document results 2Q FY01

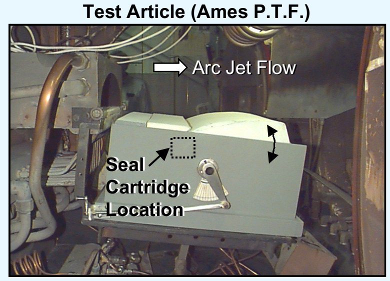
Partners

- Boeing Phantom Works/NASA GRC/NASA JSC/ NASA Ames/ HiTemp

Reference Vehicles: X–38, X–37



Arc Jet Control Surface Seal Test Article (Ames P.T.F.)



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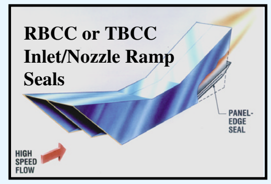
This joint NASA/Boeing effort addresses the development of high temperature structural seals for control surfaces for future highly-reusable launch vehicles. Successful development will contribute significantly to the mission goal of increasing re-use by 10 to 100 times that of the current shuttle fleet. This effort provides for the analysis, design, fabrication and testing of advanced structural control surface seal concepts. At the completion of the program, a matrix of seals and seal material combinations will have been tested for a range of aerothermal environments for a variety of advanced control surface applications (X-38, X-37, etc). See also presentation by Verzemnieks and Newquist, 2001, in this workshop proceedings for further details.

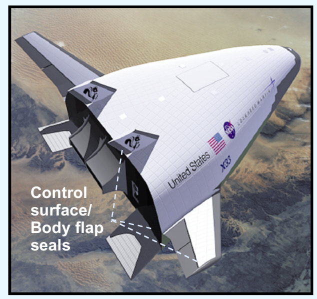
During the spring of 2001, the candidate control surface seals will be tested in the Ames 20 MW arc jet test facility under re-entry level heating rates using the arc jet test fixture model shown in figure. During arc jet operation the control surface is rotated into flow stream at angles up to 16 degrees (including 6 degree table angle) while pressures and temperatures are measured both upstream and downstream of the hinge-line gap seal. These measurements will also be used to validate an aero-thermal-structural model to be used to predict seal performance for other related programs.

NASA GRC Seal Development for 3rd Generation Space Transportation Programs: FY01 Start

- Develop hot (2500+°F), flexible, dynamic structural seals for ram/scramjet propulsion systems (RBCC, TBCC, GTX)



- Develop reusable re-entry vehicle control surface seals to prevent ingestion of hot (6000 °F) boundary layer flow



Hot, dynamic seals critical to meeting 3rd generation program life, safety, and cost goals

CD-00-80927

NASA is currently funding efforts to conduct research on advanced technologies that could greatly increase the reusability, safety, and performance of future Reusable Launch Vehicles (RLV). Research work is being performed under NASA's 3rd Generation RLV program on both high specific impulse ram/scramjet engines and advanced re-entry vehicles.

Hypersonic engines attain higher specific impulse and save weight by burning high energy fuels and using air from the environment rather than from a liquid oxygen tank. Optimizing engine performance over the wide speed range (Mach 3-10+) requires movable inlet and nozzle ramps to tailor engine flow area. High temperature (2500+F), flexible structural seals are required to prevent leakage of combustion gas into backside engine cavities.

Future RLV vehicles will be expected to operate at more aggressive re-entry conditions. High temperature seals are required to prevent ingestion of hot boundary layer gases into the control surface hinge-line locations.

NASA GRC is developing advanced structural seals for both of these needs by applying advanced design concepts made from emerging high temperature ceramic materials and testing them in advanced test rigs that are under development.

Summary

- Seals technology recognized as critical in meeting next generation aero- and space propulsion and space vehicle system goals
  - Performance
  - Efficiency
  - Reusability
  - Safety
  - Cost
- NASA Glenn is developing seal technology and/or providing technical consultation for the Agency's key aero- and space advanced technology development programs.

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NASA Glenn is currently performing seal research supporting both advanced turbine engine development and advanced space vehicle/propulsion system development. Studies have shown that decreasing parasitic leakage through applying advanced seals will increase turbine engine performance and decrease operating costs.

Studies have also shown that higher temperature, long life seals are critical in meeting next generation space vehicle and propulsion system goals in the areas of performance, reusability, safety, and cost goals.

NASA Glenn is developing seal technology and providing technical consultation for the Agency's key aero- and space technology development programs.

NASA Seals Web Sites

• **Turbine Seal Development**

+ **http:/www.grc.nasa.gov/WWW/TurbineSeal/TurbineSeal.html**
  NASA Technical Papers
  Workshop Proceedings

• **Structural Seal Development**

+ **http://www/grc.nasa.gov/WWW/structuralseal/**
+ **http://www/lerc.nasa.gov/WWW/TU/InventYr/1996Inv_Yr.htm**
  NASA Technical Papers
  Discussion

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The Seal Team maintains three web pages to disseminate publicly available information in the areas of turbine engine and structural seal development. People interested in these web sites can visit them at the addresses indicated above.

References

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